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Dated 22 March 2004

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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Cardiff Road
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1. Your reference

NIS/LMS/39708

2. Patent application number
(The Patent Office will fill in this part)

0307728.6 -3 APR 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

TESLA ENGINEERING LIMITED
Water Lane
Storrington
Sussex RH20 3EA

Patents ADP number *(if you know it)*

7015571001

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

4. Title of the invention

COIL STRUCTURE FOR MAGNETIC RESONANCE IMAGING

5. Name of your agent *(if you have one)*

fJ Cleveland

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

40-43 Chancery Lane
London WC2A 1JQ

Patents ADP number *(if you know it)*

07368855001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	7
Claim *(s)*	1
Abstract	-
Drawing *(s)*	2 + 2

10. If you are also filing any of the following, state how many against each item.

Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	-
Request for preliminary examination and search *(Patents Form 9/77)*	-
Request for substantive examination *(Patents Form 10/77)*	-
Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application.

Signature F J Cleveland — Date

fJ Cleveland — 3 April 2003

12. Name and daytime telephone number of person to contact in the United Kingdom — Dr N I Smith — 020 7405 5875

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Notes

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COIL STRUCTURE FOR MAGNETIC RESONANCE IMAGING

This invention relates to magnetic coil structures for use in magnetic resonance imaging and spectroscopy (MRIS).

Magnetic resonance imaging and spectroscopy (MRIS) systems generally comprise a plurality of cylindrical concentric coils which are located around a region within which a patient can be located. The coils include an outermost DC coil which is used to provide a strong constant magnetic field, an inner radio frequency (RF) coil arrangement which is arranged concentrically within the DC coil and a gradient coil assembly which is located between the RF coil and the outer DC coil. The gradient coil assembly is arranged to generate a time-varying audio frequency magnetic field which causes the response frequency of the nuclei of the patient to depend upon their positions within the field. The coils which generate the strong constant magnetic field are generally super-conducting coils. The presence of a patient in the magnetic field may distort the main magnetic field making it insufficiently uniform for imaging or spectroscopic measurements. A known method of counter-acting this effect is by providing multi-turn electrical windings known as shim coils and driving DC electrical currents through those windings. A typical high performance MRIS system may contain 8 to 12 shim coils, each of which is arranged to

correct an inhomogeneity with a particular spatial form. The shim coils can also be used to correct intrinsic inhomogeneities of the super-conductive magnet itself.

It is common practice to incorporate shim coils within the structure of the actively shielded gradient coil assemblies which are switched rapidly on and off in a precisely timed sequence to generate MR images. The gradient sequence contains a range of frequencies from zero to 10 kHz or more and this is often referred to as "audio frequency".

As MRIS systems have developed they have operated at higher and higher magnetic fields, eg 3T and above. As a consequence, the field strengths required from the shim coils increase proportionately resulting in coils with ever increasing numbers of turns. It is often necessary to use packs of multi-layered windings to obtain the required field strength (see Figure 1). A problem with such arrangements is that the packs become what is known as self-resonant at relatively low frequencies, eg below 20 kHz. In some cases the resonance may couple to a nearby gradient coil and its amplifier causing them to become unstable. This can disrupt the precise timing of the gradient sequence with a consequent degradation of the performance of the MRIS system.

Self resonance means that currents are flowing in sub-sections of the windings of a coil coupled by internal capacitance. Such currents may be induced even though the coil, as a whole, does not have the correct symmetry to interact with the gradient coil. Furthermore, such currents may be induced even though the coil itself is open circuit.

The present invention is concerned with techniques for overcoming or alleviating this problem.

According to a first aspect of the present invention, there is provided an electrical coil which is wound so that there are a plurality of layers with each layer having a plurality of turns, wherein an insulating material is disposed between the turns of each layer. The insulating material reduces the capacitance between the turns and this has the effect of increasing the self-resonant frequency of the coil. Thus, in the case of a shim coil for use in MRIS, the self-resonant frequency of that coil may be raised to a value beyond the band width of the amplifier associated with the gradient coils. This consequently has the effect of reducing the problem of self-resonance.

According to another aspect of the present invention there is provided an electrical coil which comprises a plurality of layers each with n turns wherein

the coil is wound so as to comprise two or more portions each of which has layers which contain fewer than n turns. By forming the coil in portions in this way inter-turn voltages are reduced and in the case of a shim coil this has the effect of increasing the self-resonant frequency. If such a coil is formed with the insulating feature of the first aspect the self-resonant frequency can be increased still further.

The invention will be described now by way of example only with particular reference to the accompanying drawings.

In the drawings:

Figure 1 is a schematic view illustrating a typical arrangement of shim coils used in MRIS.

Figure 2A is a cross-section through a single block of such shim coil.

Figure 2B is a cross-section illustrating one embodiment in accordance with the present invention; and

Figure 2C is a cross-section illustrating another embodiment in accordance with

the present invention.

Figure 1 shows schematically how shim coils are particularly arranged into packs or blocks for use in MRIS systems. As has been explained, currents can flow in sub-sections of the windings of such coils coupled by internal capacitance and this is illustrated in Figure 2A of the drawings which shows the inter-turn connections. This Figure shows three layers 10, 11, 12 each having a number of turns 15. The illustrated inter-turn connections have the effect of producing so-called self-resonance which can affect the performance of the MRIS system.

Figure 2B illustrates a first embodiment of the present invention for reducing or alleviating this self-resonant effect. In this first embodiment there are illustrated three layers 10, 11 and 12 of windings each having a number of turns 15. The coil has been formed in such a way that each layer of turns is separated from the next layer by a layer of insulating material 16. The layer of insulating material may for example, be a layer of glass cloth having a thickness of 0.2 mm. The presence of the layer 16 has the effect of increasing the self-resonant frequency of the coil.

Considering as an example a multi-layer pack of windings having five layers

with 27 turns per layer, this gives 135 turns in total. For minimum resistance, the windings will typically be made from rectangular section lacquered wire and be very closely packed as shown in Figure 2.

For such an example, a layer of glass cloth 16 0.2mm thick has the effect of increasing the self-resonant frequency from 14.75kHz to 23.0kHz taking it outside the typical bandwidth of the amplifier of the gradient coils.

A second embodiment of the present invention is illustrated in Figure 2C of the drawings. A pack such as that shown in Figure 2A of the drawings which has five layers with 27 turns per layer can have up to 54 turns between the turns in adjacent layers. This means that substantial internal voltages can build up inside the coil and this leads to high capacitive stored energy.

This effect is reduced by structuring the coil as shown in Figure 2C of the drawings. The principle illustrated in Figure 2C is to divide the coil into multiple portions (20, 21) so that, for example, for the specific coil referred to above, there is one portion having 13 turns in five layers and another portion having 14 turns in five layers. This means that the internal voltages referred to above are significantly reduced and again, this has the consequence of increasing the self-resonant frequency. The coil can be divided into as many

portions as are deemed necessary to provide the appropriate increase in self-resonant frequency. Advantageously, the technique of forming the coil in portions can be used in conjunction with the technique of using insulating material between the layers in the manner illustrated in Figure 2C. For the example of the coil given above, the self-resonant frequency can be increased to 46 kHz. It will be appreciated that further increases in resonant frequency can be achieved by sub-dividing the coil into more portions than those illustrated in Figure 2C.

The techniques for increasing the self-resonant frequency have been described above in relation to axial shim coils. It will be appreciated that they are applicable equally to other coil types such as transverse shim coils.

CLAIMS

1. An electrical coil which is wound so that there are a plurality of layers with each layer having a plurality of turns, wherein an insulating material is disposed between the turns of each layer.

2. An electrical coil according to claim 1 wherein the insulating material is glass cloth.

3. An electrical coil which comprises a plurality of layers each with n turns wherein the coil is wound so as to comprise two or more portions each of which has layers which contain fewer than n turns.

4. An electrical coil according to claim 4 wherein insulating material is disposed between the turns of each layer.

5. An electrical coil according to any one of claims 1 or claim 4 wherein the coil is a shim coil for an MRIS apparatus.

6. An electrical coil substantially as hereinbefore described with reference to and as shown in Figure 2B or Figure 2C of the accompanying drawings.

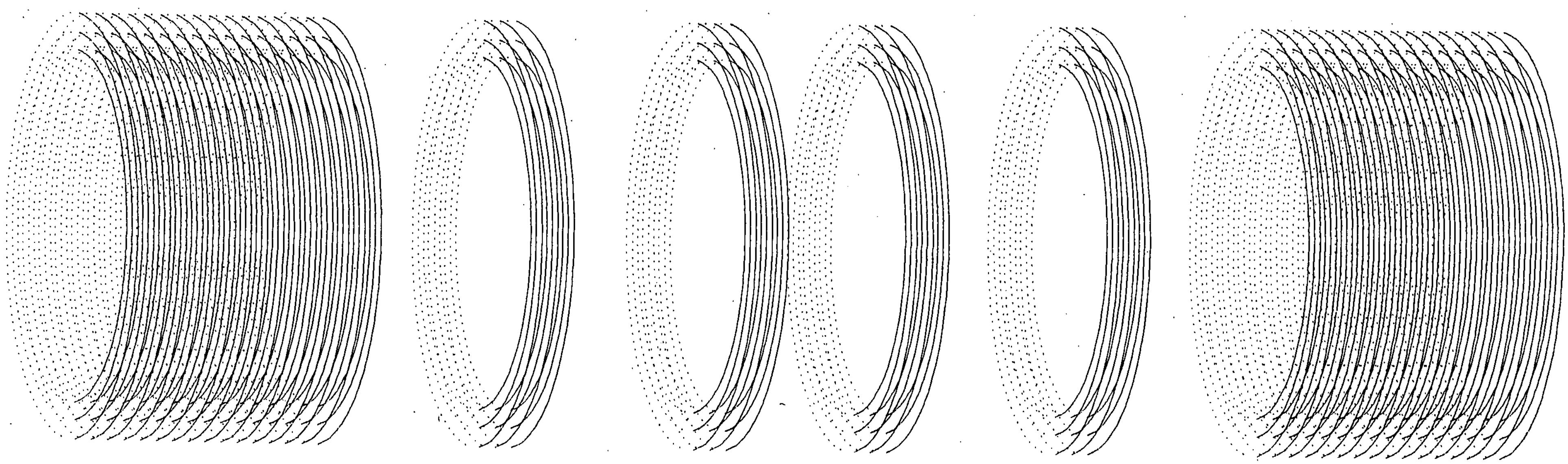

Fig. 1

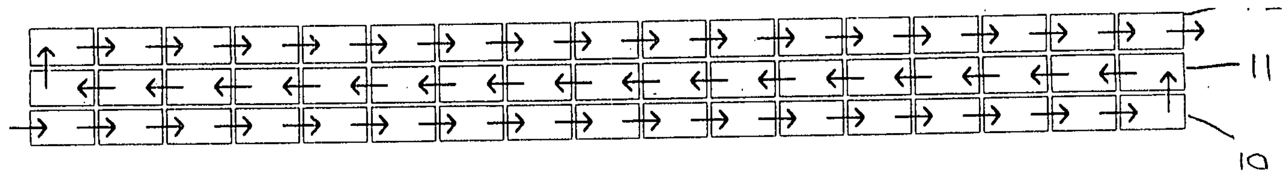

Fig.2a: Cross-section through single coil block showing inter-turn connections

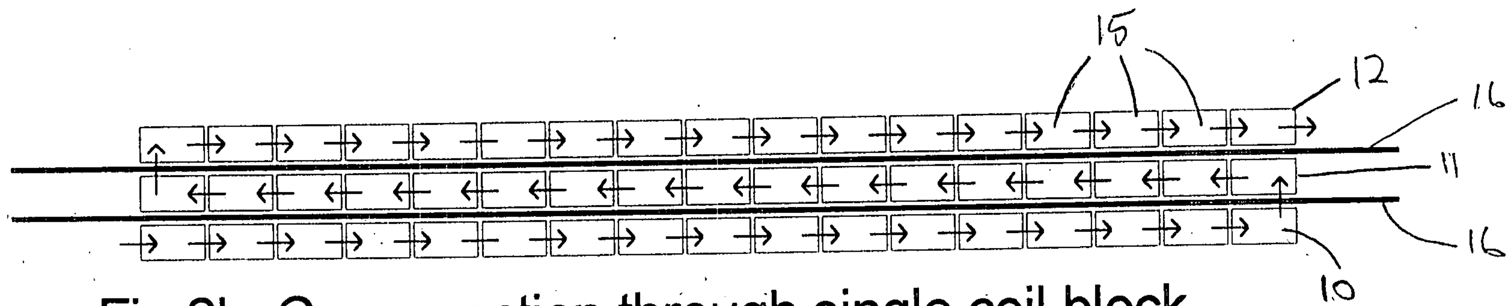

Fig.2b: Cross-section through single coil block showing inter-turn connections, with added inter-layer insulation

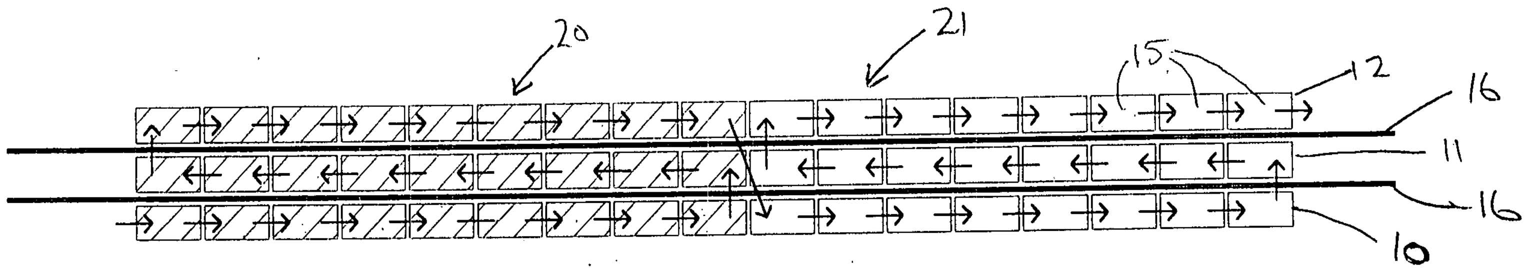

Fig.2c: Cross-section through sub-divided coil block showing inter-turn connections, with added inter-layer insulation. Hatching shows one sub-block.